

A SOLUTION FOR THE SPACE SHUTTLE HIGH TEMPERATURE ANTENNA PROBLEM

E. A. Kuhlman

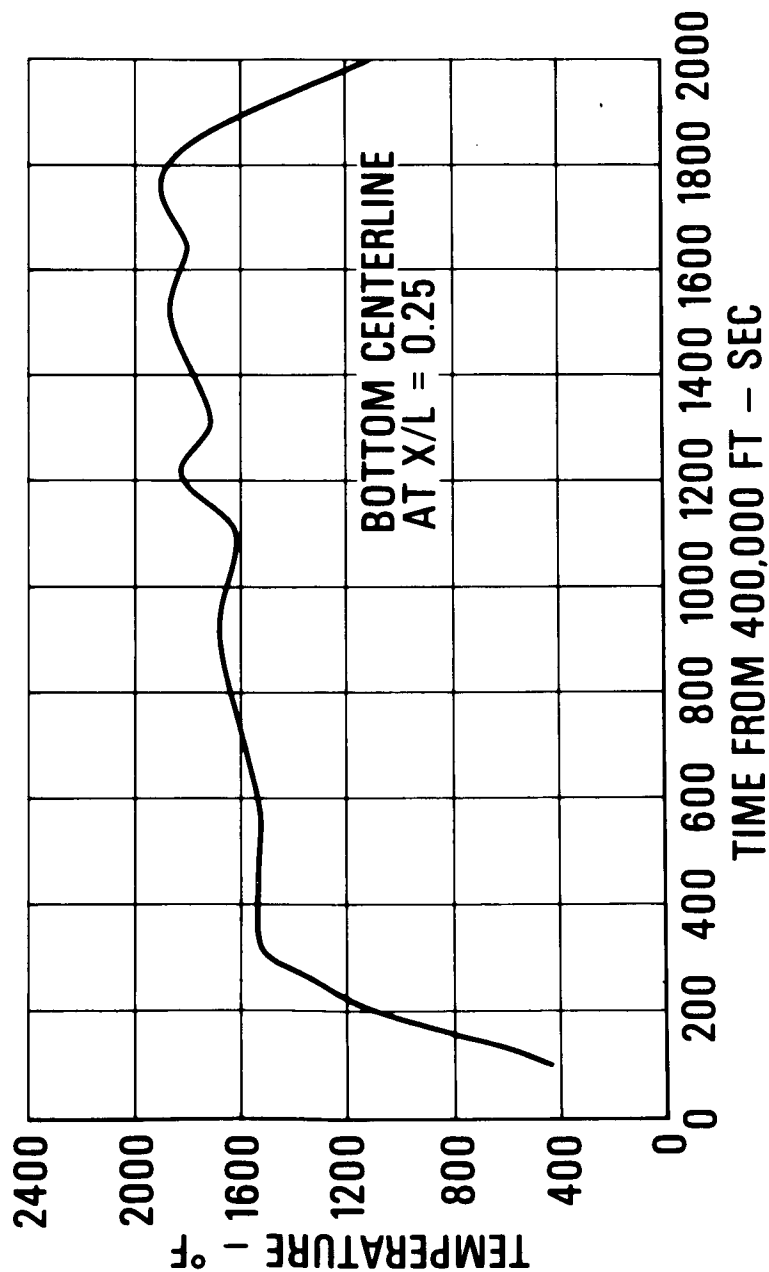
McDonnell-Douglas Corporation
St. Louis, Missouri

The development of high temperature antennas is one of the more difficult Space Shuttle problems. The avionics systems on-board the Space Shuttle orbiter and booster use frequencies which are used on commercial and military airplanes. The high temperature antennas previously developed for reentry vehicle applications are for other frequencies, and were designed for one shot application. Therefore, the techniques which have been developed for high temperature reentry vehicle antennas may not be directly applicable to the reusable requirements of Space Shuttle. This leaves the designer in the position of applying both new and old techniques to antenna types which have not previously been designed for operation at reentry temperatures.

SPACE SHUTTLE ORBITER TEMPERATURES

The equilibrium temperature profile on the underside of the Space Shuttle orbiter in an area considered for the location of some of the antennas is shown in this slide. This temperature profile represents the maximum thermal environment expected for the orbiter antenna systems.

REENTRY EQUILIBRIUM TEMPERATURES Delta Orbiter



TECHNICAL APPROACH

Two basic technical approaches are possible to solve the Space Shuttle high temperature antenna problems. One is the use of a high temperature antenna which can be mounted directly in the Space Shuttle skin. The other is the use of an off-the-shelf low temperature antenna covered with a dielectric window which provides thermal protection for the antenna and has good RF transmission properties.

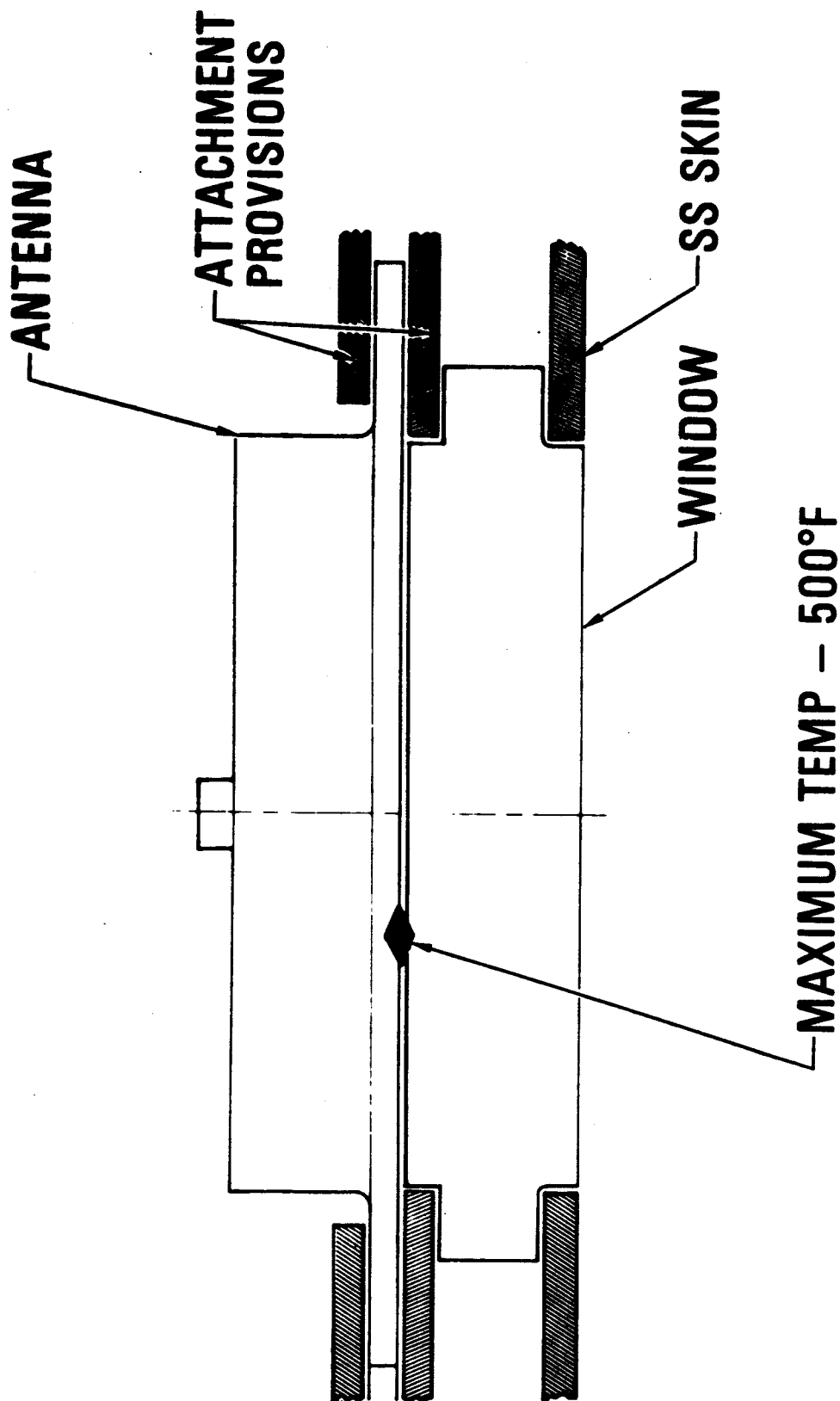
- HIGH TEMPERATURE ANTENNA
- LOW TEMPERATURE ANTENNA/HIGH TEMPERATURE WINDOW

The primary factors considered in determining which technical approach to take are shown in this slide. After considering each of these items for each of the technical approaches shown on the last slide, the latter off-the-shelf approach was selected for further study. This approach gives a good separation of the electrical and the environmental problems, and does not appear to require state-of-the-art advances in material properties or fabrication techniques in order to solve the problems.

- DEVELOPMENT AND RECURRING COSTS
- DEVELOPMENT STATUS
- FUNCTIONAL REQUIREMENTS
- MATERIAL REQUIREMENTS AND PROPERTIES
- PRODUCIBILITY
- SPACE SHUTTLE INTEGRATION
- REUSABILITY
- PROBABILITY OF SUCCESS

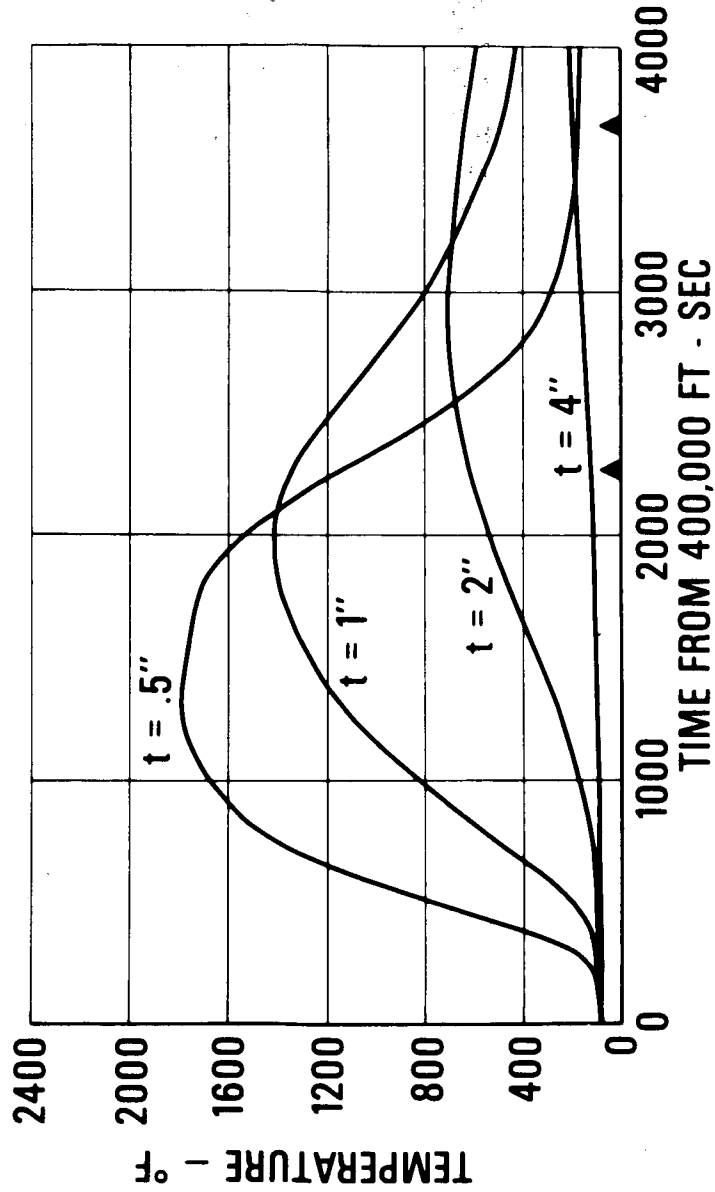
ANTENNA/WINDOW CONFIGURATION

A conceptual design of a typical Space Shuttle antenna installation is shown in this slide.
The relationship of the antenna and window is shown.



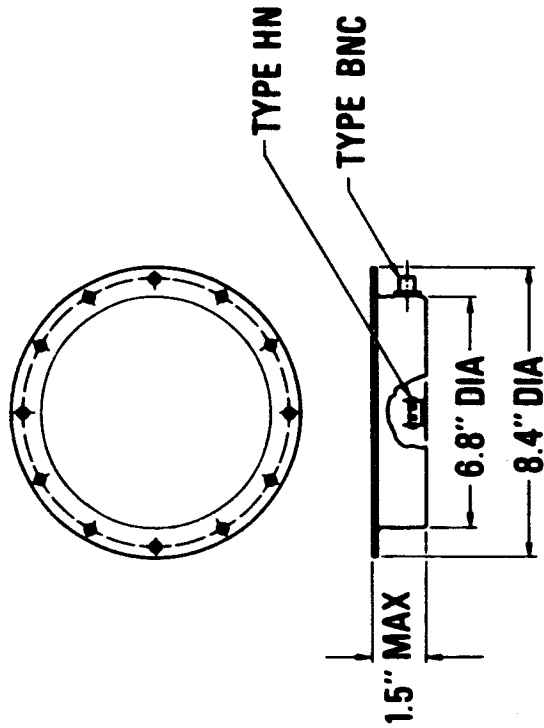
ANTENNA WINDOW BACKFACE TEMPERATURES

The results of calculations to determine the window thickness are shown in this slide. The results were obtained using shuttle thermal inputs for a typical design trajectory and the thermal properties of slip cast fused silica (SCFC). From these results it can be seen that a window of SCFC 3 to 3-1/2 inches thick will maintain a window backface temperature of 500°F or less. The results would, of course, be different for a different window material.



TEST ANTENNA

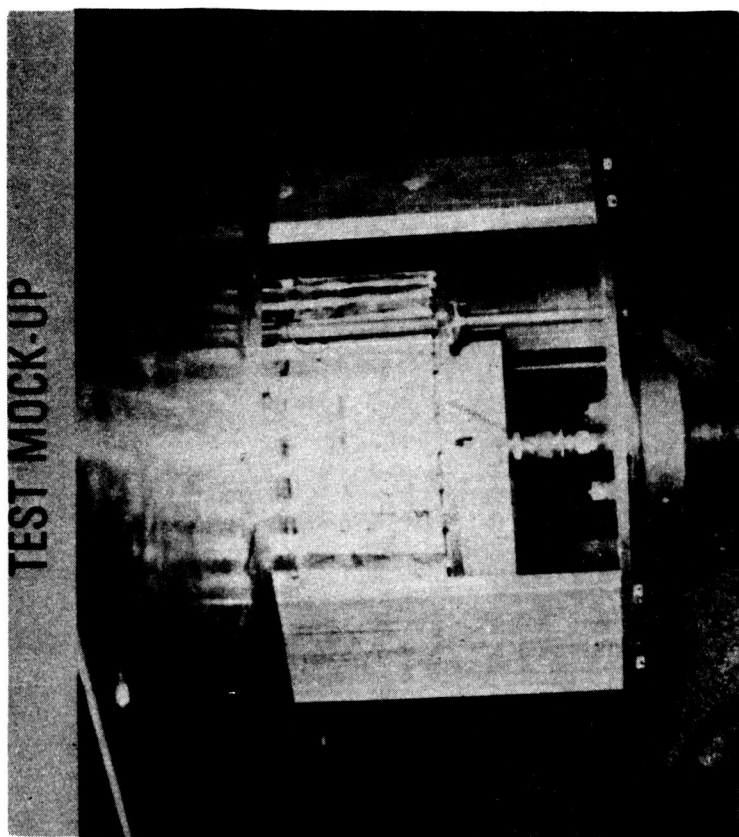
An L-Band annular slot antenna used to obtain the test results to be described is shown in this slide. This antenna is a standard AT-740 and is readily available for operational temperatures of 400°F or less. It has also been designed to operate at a temperature of 500°F. The AT-740 operates at frequencies from 960 to 1220 MHz and is used with DME and ATC systems. The radiation pattern is basically the same as that obtained from a quarter wave stub antenna.



**DME/ATC
L-BAND (960-1220 MHz)**

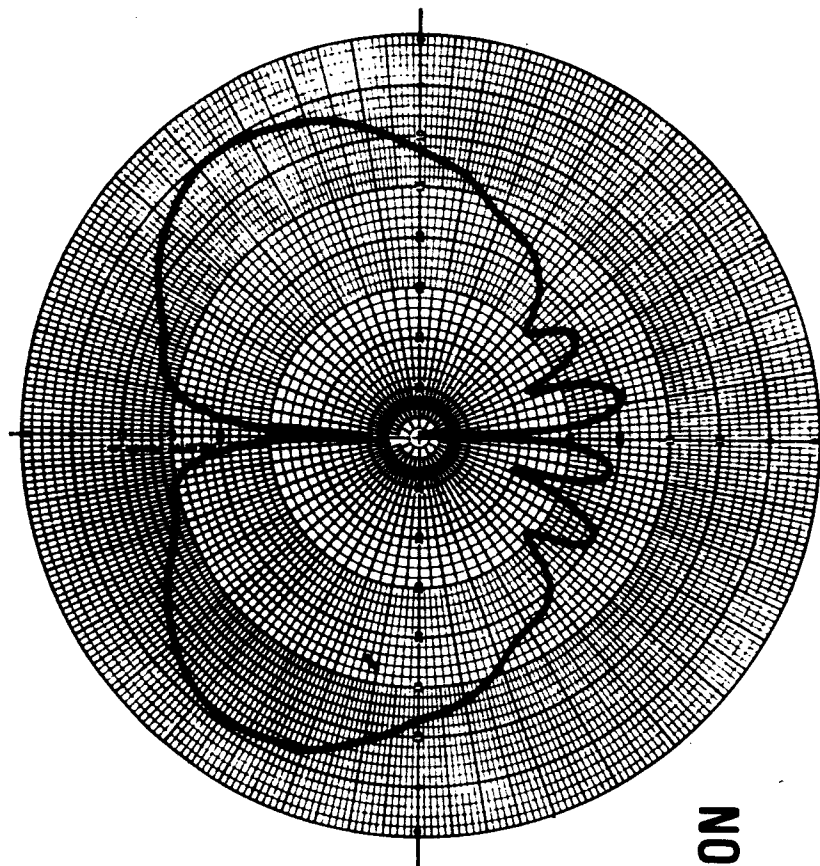
TEST CONFIGURATION

The test mock-up simulates the essentials of a typical space shuttle orbiter antenna installation. Provisions were made to permit testing with different window thicknesses. The ground plane can also be replaced with a different aperture size to facilitate testing different window diameters. Both radiation patterns and impedance can be measured using this mock-up.



REFERENCE RADIATION PATTERNS

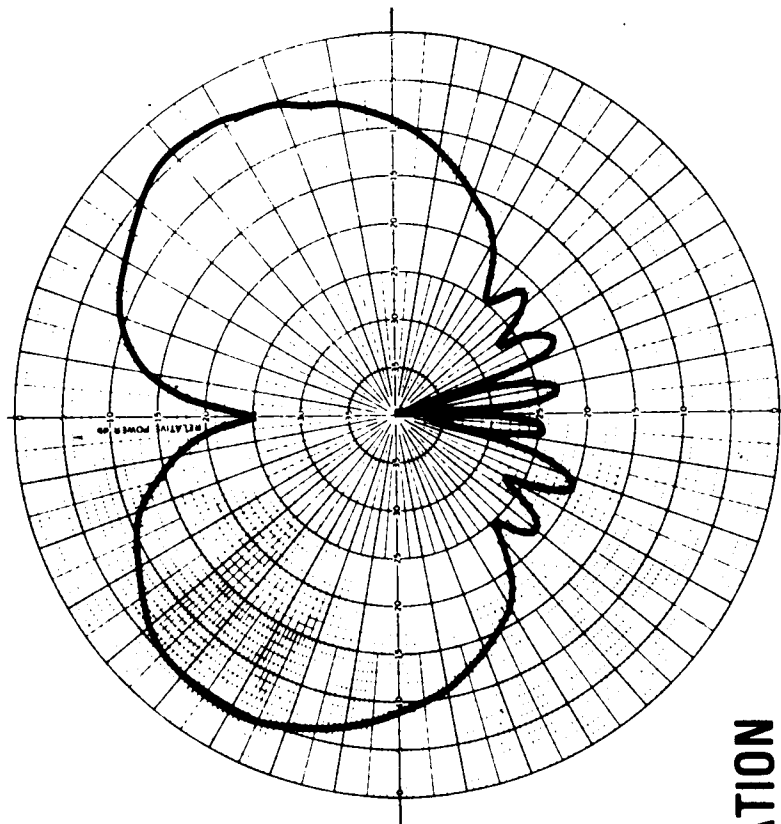
A typical radiation pattern of the antenna flush mounted in a ground plane is shown for the principal polarization at 960 MHz. The antenna was not covered with an additional window, and the ground plane had the same dimensions as the mock-up described. This pattern serves as a reference for evaluating the degree of degradation attributable to the window in the simulated shuttle installation.



θ POLARIZATION
 $f = 960 \text{ MHz}$

REFERENCE RADIATION PATTERNS

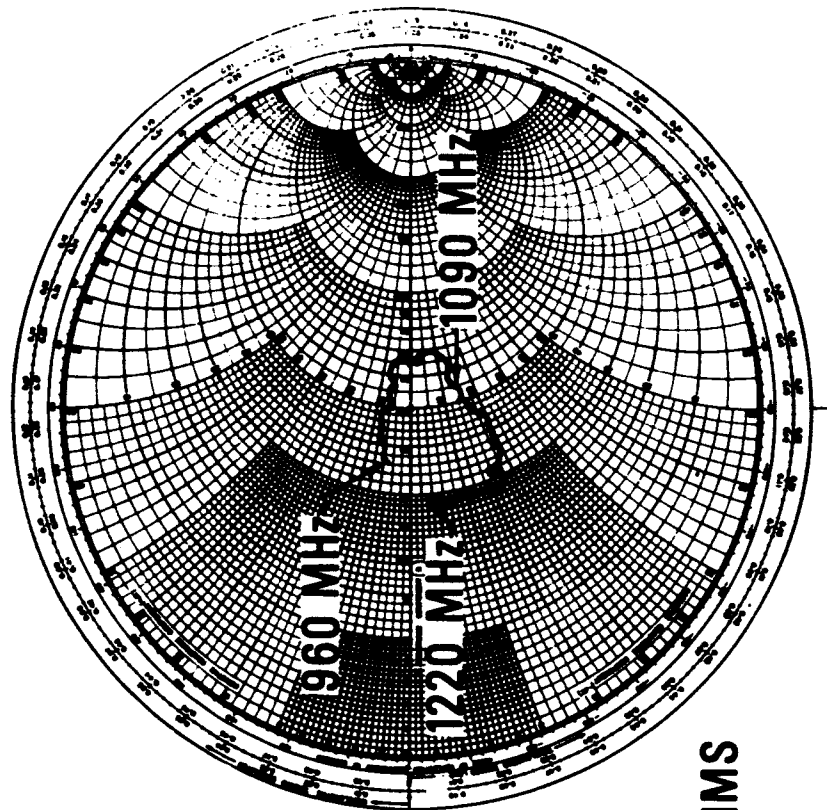
A typical radiation pattern is shown for the principal polarization at 1220 MHz. The configuration and conditions were the same as those stated for the previous slide.



θ POLARIZATION
 $f = 1220 \text{ MHz}$

REFERENCE IMPEDANCE DATA

The impedance characteristics of the antenna for the configuration described for the two previous slides are shown in this slide. The maximum VSWR is 2.05:1.

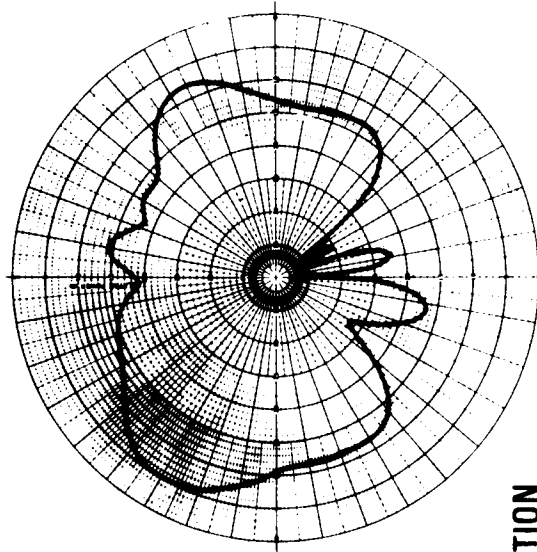


$Z_0 = 50 \text{ OHMS}$

RADIATION PATTERNS

WINDOW EDGES OPEN

Radiation pattern measurements with the antenna covered with a window 3.5 inches thick show considerable distortion in the antenna pattern. This was expected since the window edges were not covered with an electrical conductor and energy could be radiated through the window edges behind the ground plane and scattered by the structure supporting the antenna both behind the ground plane and through the window. Therefore, it was concluded that the window edges must be covered with an electrically conducting surface to eliminate the pattern distortion caused by the antenna support structure.

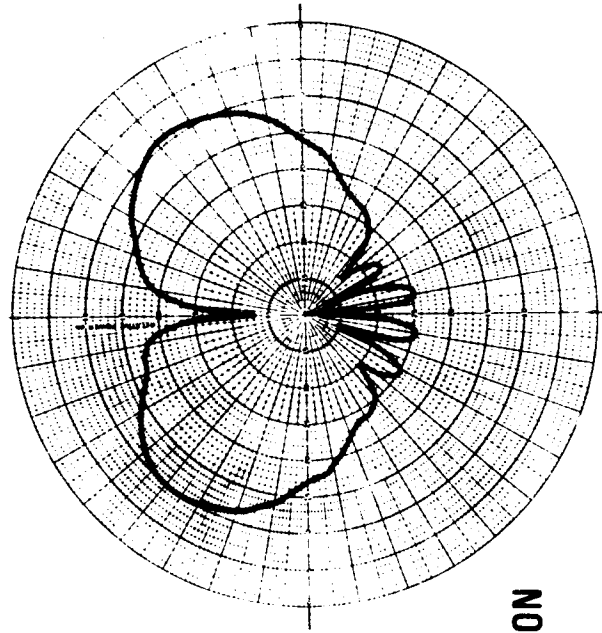


θ POLARIZATION
 $f = 960 \text{ MHz}$

RADIATION PATTERNS

WINDOW EDGES ENCLOSED

Radiation pattern measurements with the window edges entirely enclosed by an electrically conducting material show that the window thickness has very little effect on the shape of the basic antenna pattern. The pattern shown in this slide was measured at 960 MHz. The differences in gain observed are accounted for by considering the transmission characteristics of the window and an increase in the antenna VSWR. This configuration is essentially a dielectrically loaded circular waveguide excited in the TM_{01} mode with an annular slot antenna. The conductor enclosing the window edges was attached to both the ground plane and the antenna mounting flange.

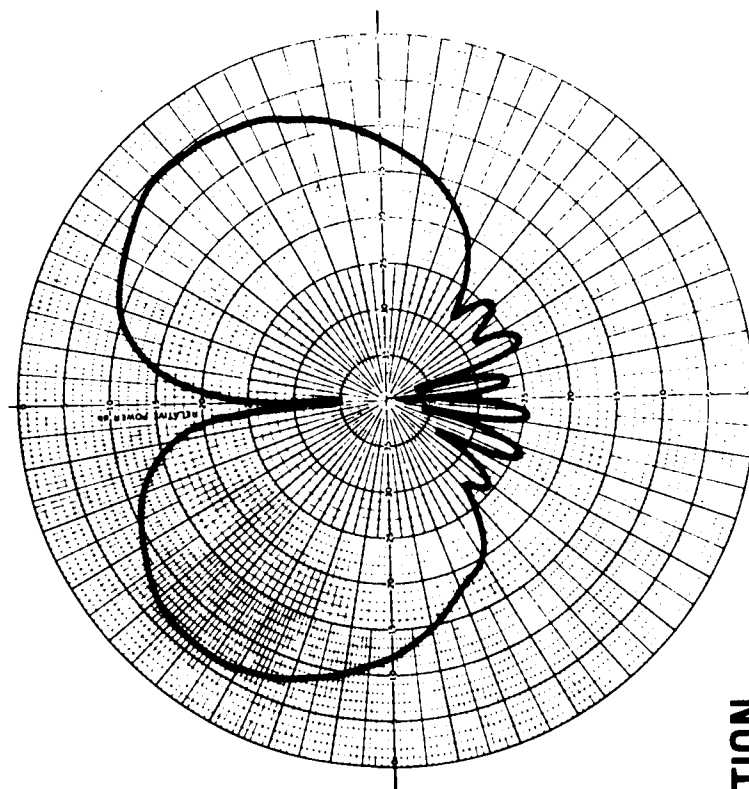


θ POLARIZATION
 $f = 960 \text{ MHz}$

RADIATION PATTERNS

WINDOW EDGES ENCLOSED

A radiation pattern is shown for the principal polarization at 1220 MHz. The configuration and conditions were the same as those stated for the previous slide.

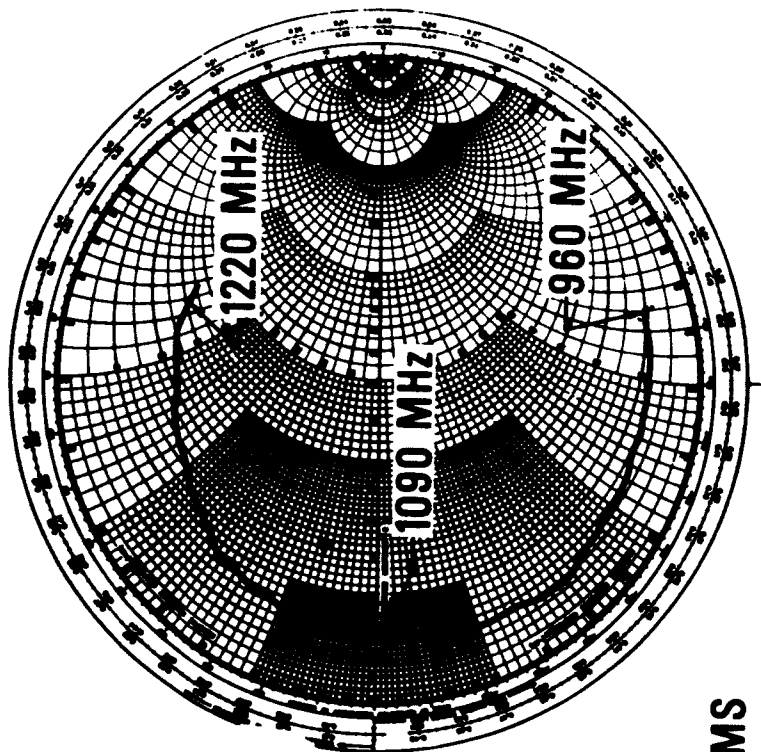


θ POLARIZATION
f = 1220 MHz

ANTENNA/WINDOW IMPEDANCE

WINDOW EDGES ENCLOSED

The impedance for the antenna/window configuration described for the previous two slides is shown in this slide. The VSWR is increased over the entire frequency range. Techniques to obtain an impedance match comparable to the reference condition are being considered. Some revisions in this basic antenna matching network may be required to maximize the system efficiency.

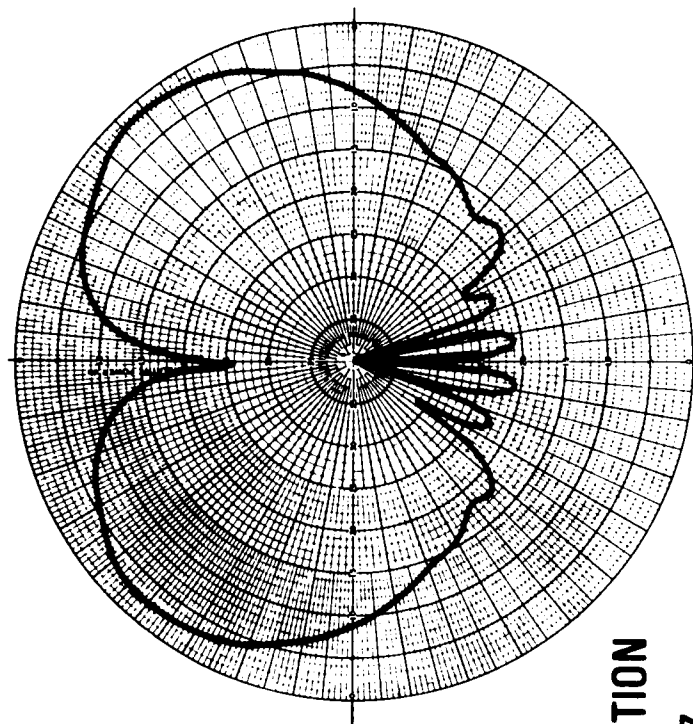


$$Z_0 = 50 \text{ OHMS}$$

RADIATION PATTERN

WINDOW EDGES ENCLOSED WITH PERIODIC STRIPS

Radiation pattern measurements were made with the window edge enclosure changed to 1/2 inch strips spaced approximately 1/2 inch apart to reduce heat conduction paths. The pattern shown in this slide is essentially the same as that obtained with a continuous window edge enclosure. The strips were attached to the ground plane and the antenna mounting flange. This pattern was measured at 1220 MHz. Similar results were obtained at other applicable frequencies.

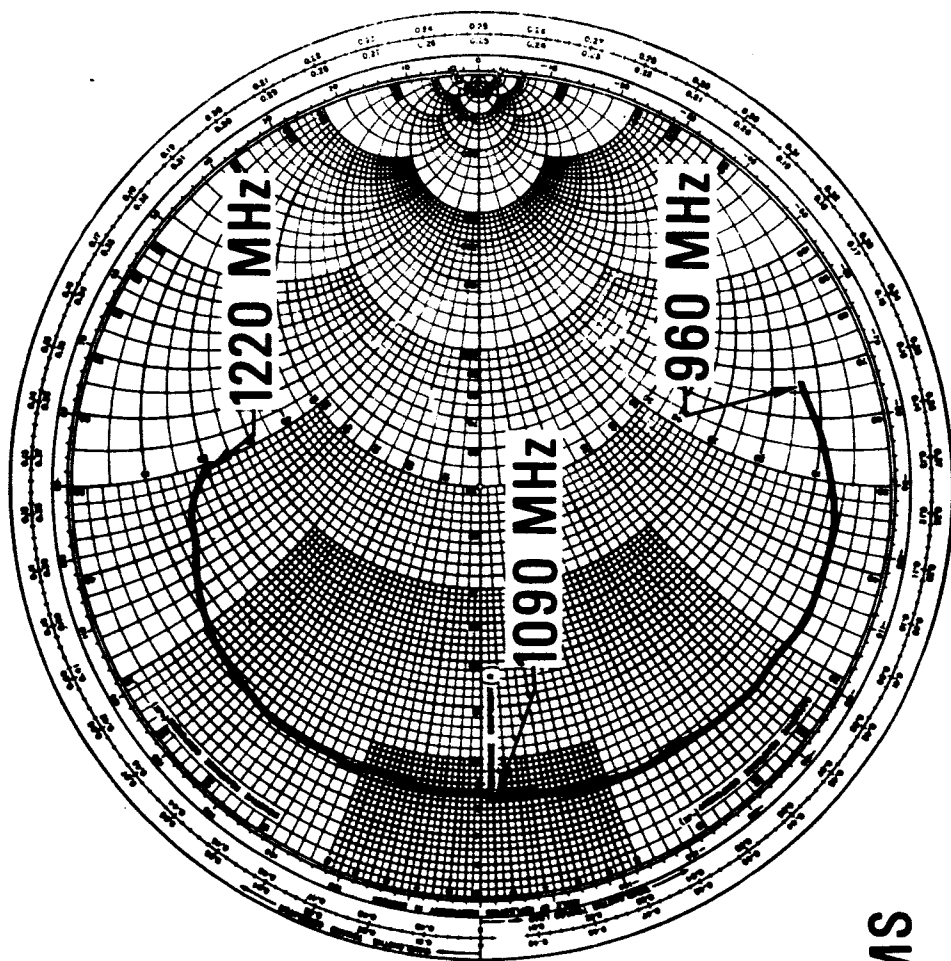


θ POLARIZATION
 $f = 1220 \text{ MHz}$

ANTENNA/WINDOW IMPEDANCE

WINDOW EDGES ENCLOSED WITH PERIODIC STRIPS

The impedance of the antenna/window configuration with the periodic window enclosure is essentially the same as that obtained with the continuous enclosure.



$$Z_0 = 50 \text{ OHMS}$$

RESULTS AND CONCLUSIONS

The results given in this slide lead to the conclusion that the antenna/window approach will provide a solution for the Space Shuttle high temperature antenna problem. However, the off-the-shelf antenna may require modification of its matching network to meet the required system impedance match, if future work does not produce a simple and efficient method for obtaining a matched system external to the antenna. At worst, modifying the internal configuration of an existing antenna does not appear to be nearly as difficult as the development of an antenna designed to operate at high temperatures without the benefit of thermal protection.

RESULTS

- EXCELLENT RADIATION PATTERNS WERE OBTAINED WITH A THICK WINDOW COVERING AN ANNULAR SLOT ANTENNA
- A WINDOW EDGE ENCLOSURE WAS REQUIRED
- THE ANTENNA IMPEDANCE WAS AFFECTED BY THE WINDOW AND WINDOW EDGE ENCLOSURE

CONCLUSIONS

- THE ANTENNA/WINDOW APPROACH WILL PROVIDE A SOLUTION FOR THE SPACE SHUTTLE HIGH TEMPERATURE PROBLEM
- ADDITIONAL WORK IS REQUIRED TO DETERMINE THE BEST APPROACH TO ACCOMPLISH THE REQUIRED ANTENNA/WINDOW IMPEDANCE MATCH